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FIRE EXTINGUISHING PERFORMANCE OF FIREBANE ON JP-8 JET FUEL FIRES

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14. ABSTRACT
Firebane 1115 and Firebane 1179 fire extinguishing agents were evaluated in scenarios typical of flight line fires. Undiluted Firebane has a freeze point below -20 F and is described as having low corrosion in brass and aluminum and acceptable corrosion in carbon steel and hot-dipped galvanized steel. Evaluations included JP-8 pool fires and three-dimensional JP-8 engine nacelle rear engine fires, which consisted of a 4-gal/min running fuel fire and 100-ft^2 pool fire below the engine nacelle. The agents were assessed on extinguishment time, volume of agent used, and effectiveness on the fires. Compressed air foam systems were used for the evaluations, the recommended agent delivery method for Firebane. At full concentration neither Firebane 1115 or 1179 were effective at extinguishing rear engine fires. Firebane 1115 mixed 10 percent by volume with water was effective at extinguishing the simulated engine fire, and Firebane 1115 mixed 50 percent by volume with water was also effective on the engine fire but took more time and agent than the 10-percent mix. Firebane 1115 at full concentration and diluted 10 percent by volume with water extinguished JP-8 pool fires.

15. SUBJECT TERMS
Firebane, JP-8 fire, aviation fuel fire, aircraft fire, aircraft firefighting, three-dimensional fire, pool fire

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1. SUMMARY

The current flight line extinguisher used by the Air Force, Navy, and at civilian airports in the U.S. is the Amerex 150-lb extinguisher filled with the fire suppression agent bromochlorodifluoromethane (Halon 1211). The production of Halons has been banned since January 1, 1994, as a condition of the Montreal Protocol on ozone depleting substances. The U.S. Army (USA) has transitioned to compressed air foam (CAF) systems using Aqueous Film Forming Foam (AFFF) concentrate.

The Army Material Command is evaluating commercially available aqueous firefighting agents for military use. The agent Firebane (formerly Arctic Fire-Freeze) is manufactured by Global Safety Labs (GSL), Inc., a distributor of fire protection and suppression products. Firebane 1115 in the GSL "Stinger" 20-gal extinguisher is Underwriters Laboratories (UL) rated 10B. GSL states that the Stinger CAF extinguisher operates at a flow rate of 7.5 gal/min and a 22:1 expansion ratio. A straight bore nozzle is used for agent application.

Firebane agents 1115 and 1179 were evaluated for their performance against JP-8 fires typical of flight line operations. The fire scenarios used for evaluations were JP-8 pool fires and three-dimensional JP-8 engine nacelle tailpipe fires, which consists of a 4 gal/min running fuel fire and 100-ft^2 pool fire below the engine nacelle. Baseline tests using AFFF were also conducted. The agents were assessed on extinguishment time, agent used, and effectiveness on the fires. The data collected will be used by the Army to compare the performance of Firebane to that of AFFF in typical flight line firefighting applications.

Firebane 1115 was not effective at extinguishing engine nacelle tailpipe fires in its undiluted, freeze protected condition; however, the agent was much more effective when diluted with 50 percent or 90 percent water. The fastest extinguishment times were obtained at the dilution of 10 percent Firebane 1115 and 90 percent water. Army-standard extinguishers using 3% AFFF solution extinguished this fire faster using less agent.

The average area density of Firebane 1115 (100 percent) required for extinguishment of pool fires was 0.23 gal/ft^2. At a 10-percent concentration, the density of Firebane solution required for extinguishment was 0.057 gal/ft^2. The density of Army-standard 3% AFFF solution required to extinguish this fire was 0.053 gal/ft^2.

Firebane 1179 was not effective at extinguishing the 100-ft^2 pool fire feature of the engine nacelle test protocol, but the agent was successful in extinguishing the tailpipe fire alone at an average flow rate of 33 gal/min, but less successful, with longer extinguishment times at an average flow rate of 11 gal/min. The Army-standard 3% AFFF solution successfully extinguished the 100-ft^2 pool fire feature of the engine nacelle test protocol.

2. INTRODUCTION

2.1. Background

The purpose of this project was to evaluate the performance of Firebane 1115 and Firebane 1179 fire extinguishing agents in fire scenarios typical of flight line fires and to provide some comparisons to AFFF.

The current flight line extinguisher used by the Air Force, Navy, and at civilian airports in the U.S. is the Amerex 150-lb extinguisher. It employs bromochlorodifluoromethane (Halon 1211), the production of which has been banned since January 1, 1994, as a condition of the Montreal Protocol on ozone depleting substances. Recycling of Halon 1211 has thus far been allowed for critical applications in the U.S. military, including flight line extinguishers. A complete phase out of Halon 1211 in flight line extinguishers in the European Union (EU), which directly affects U.S. air bases in the EU, has been set for 2016.

Non-corrosive, non-conductive agents do exist that the Environmental Protection Agency (EPA) allows as substitutes for Halon 1211, however the agents also have global warming potential (GWP) > 1 and/or ozone depletion potential (ODP) > 1. Owing to their high GWP/ODP potentials, there is a concern that these agents will also be banned by the EPA within the foreseeable future, necessitating a repeat of the process to identify a replacement agent and system.

The USA has transitioned to CAF systems using military specification (MILSPEC), MIL-F-24385F[1] AFFF concentrate or freeze protected AFFF in low temperature environments. Major drawbacks to aqueous foam system are electrical conductivity of the water-based agent and the requirement for freeze protection at many operating locations, necessitating the use of non-concentrate firefighting agents or additives like seawater or propylene glycol which can make the solution corrosive to internal engine parts and to electronic equipment.

The Army Material Command is evaluating commercially available aqueous firefighting agents for military use. The agent Firebane (formerly Arctic Fire-Freeze) is manufactured by GSL, Inc., a distributor of fire protection and suppression products. According to the GSL website Firebane "provides an advanced fire extinguishment and thermal barrier unlike any other on the market. In fact, Firebane is the first and only aqueous-based agent to be certified to UL standards for Class A, B and D fires, suppressing fire faster than any other product on the market." [2] Undiluted Firebane has a freeze point below -20 °F and is described as having low corrosion in brass and aluminum and acceptable corrosion in carbon steel and hot-dipped galvanized steel[2]. Data given in this report will be used by the Army to compare the performance of Firebane to that of AFFF in typical flight line firefighting applications.

Firebane 1115 in the GSL "Stinger" 20-gal extinguisher is UL rated 10B. GSL states that the Stinger CAF extinguisher operates at a flow rate of 7.5 gal/min and a 22:1 expansion ratio. A straight bore nozzle is used for agent application.

2.2. Scope

Firebane formulas 1115 and 1179 were evaluated for their performance against JP-8 fires typical of flight line operations. The fire scenarios used for evaluations were JP-8 pool fires and three-dimensional JP-8 engine nacelle rear engine test (tailpipe) fires, which consists of a 4 gal/min running fuel fire and 100-ft^2 pool fire below the engine nacelle. The agents were assessed on extinguishment time, volume of agent used, and effectiveness on the fires.

3. METHODS, EQUIPMENT, AND PROCEDURES

All of the evaluations were performed at Air Force Research Laboratory's fire research facility at Tyndall AFB, FL, part of the Materials and Manufacturing Directorate, Airbase Technologies Division. The fires were fought by a professional Department of Defense International Fire Service Accreditation Conference certified firefighter with over 33 years of experience.

3.1. Firefighting Agents

Firebane 1115 and 1179 were evaluated in these fire suppression tests. The agents are typically used in extinguishers at 100-percent concentration, and the initial plan was to conduct all evaluations with the agent at full concentration. Early on in these evaluations it was determined that agent performance was poor on JP-8 fires. The manufacturer then recommended diluting the 1115 agent with 50 percent and 90 percent water. A majority of the tests were subsequently conducted with the agent diluted. In their pure form, the agents have pour points of -49 °F and -81 °F respectively. A side effect of diluting the agent with water is that the freezing point becomes closer to the freezing point of water as more water is added. The freezing point of the diluted agent was not measured. Density of the agents and the diluted agents was measured at room temperature using a Mettler Toledo Densito 30PX instrument.

Fire tests were also conducted with 3-percent MILSPEC AFFF mixed at 3 percent for comparison.

3.2. Firefighting Agent Delivery Systems

Two delivery systems, a Combined Agent Fire Fighting System (CAFFS) and a modified Tri-Max 30, were used for the evaluations of the two Firebane agents. Both systems were chosen for these evaluations because they produce CAF, the recommended agent delivery method for Firebane. Both delivery systems used compressed nitrogen gas for foam expansion and to discharge the agents.

3.2.1. CAFFS

The CAFFS system, shown in Figure 1, is designed to discharge CAF and/or dry chemical. It includes a 200-gal capacity liquid agent tank, two 150-ft lengths of 1-in diameter hose, a smooth bore nozzle, high pressure compressed gas tanks, an adjustable valve for air injection into the foam stream to produce CAF, and a Testcom regulator. The unit was pressurized to 180 lb/in^2 (gauge) and the average flow rate with AFFF at 50-percent air injection was 43 gal/min. The first two tests with Firebane were conducted with a 50-percent air injection setting for CAF. The remaining Firebane tests were conducted with a 100-percent air injection setting.

Figure 1. CAFFS unit positioned on scales

3.2.2. Modified Tri-Max 30

The Tri-Max 30, shown in Figure 2, includes a 30-gal tank, a 50-ft length of 1-in diameter hose, an air mixing chamber for CAF, and a smooth bore nozzle. This unit was modified by replacing the original nitrogen regulator with a Testcom regulator, model 44-1312-1082-255, and by replacing the small external high pressure nitrogen cylinders with larger K-size external nitrogen cylinders. The unit was pressurized to 135 lb/in^2 (gauge), and the average flow rate of this unit with AFFF was 15 gal/min.

Figure 2. Modified Tri-Max 30 extinguisher positioned on scale

3.3. Agent Flow Rate Measurement

Digital scales were used to measure the weight of the extinguishers before and after each test. Two Intercomp model PT-300 scales were used to measure the weight of the CAFFS. This scale reads in 10-lb increments and has an accuracy of $\pm$1percent of reading. A Transcell Technology Incorporated model TI-500E scale was used to measure the weight of the Tri-Max 30 during evaluations. This scale reads in 0.1-lb increments and has an accuracy of $\pm$2 lb. The measured density of the agents, the recorded weights, and total agent discharge time were used to calculate the flow rate and the amount of agent used per test. An intermittent problem with the Intercomp PT-300 scale caused it to shut off during some evaluations, and as a result the quantity of agent discharged could not be measured and recorded and thus flow rates could not be calculated for some of the trials. For some of the AFFF measurements a scale was not used, and flow rate was instead calculated by dividing the known extinguisher volume by the total discharge time for a full extinguisher.

3.4. Fire Evaluation Procedures

3.4.1. Pool Fire Procedures

Firebane 1115 was evaluated on JP-8 pool fires in the AFRL Test Range I Fire Pit using the modified Tri-Max 30 extinguisher. Pool fires were conducted inside an adjustable ring that measured 10 ft in diameter (79 ft^2) or 15 ft in diameter (177 ft^2). JP-8 was floated on top of water inside the ring, as shown in Figure 3, to a depth of 0.5 in such that there was a freeboard of 1 to 2 in. The fuel was ignited with a propane torch. After the flames spread across the entire fuel surface, the fuel was allowed to burn for an additional 20 s (pre-burn) before agent application began. Since the performance of the extinguisher/agent combination on pool fires was unknown before testing began, the goal was to first estimate minimal agent application rates that could

extinguish a fire to ensure that the fire was not too small or too large for the extinguisher/agent combination (agent is typically not used efficiently if the fire is too small). Tests were conducted when the wind speed was less than 10 mi/h. The weight of the extinguisher was recorded before and after each test.

Figure 3. The 15-ft diameter pool fire ring being filled with JP-8

After the pre-burn, the firefighter was allowed to attack the fire. Once all the fire within the ring was extinguished, agent application ceased. The time required to extinguish the fire and the final weight of the extinguisher were recorded. Total agent discharged and average flow rate were calculated based on the agent discharge time and the before and after extinguisher weight measurements.

3.4.2. Engine Nacelle Tailpipe Fire Procedures

Engine nacelle tailpipe fires were conducted using an F100 engine nacelle mockup. A test protocol was previously developed to evaluate performance of Air Force flight line extinguishers and is detailed in reports AFRL-ML-TY-TR-02-4540 [4] and AFRL-ML-TY-TR-2002-4604[5].

Tests were conducted when the wind was less than 10 mi/h. The engine nacelle was pre-heated to 550 °F or greater by burning fuel sprayed inside the nacelle. The fuel was turned off and the nacelle was allowed to cool. During the cool down period, the initial weight of the extinguisher was recorded. When the nacelle temperature measured 475±25 °F fuel flow was adjusted to 4 gal/min, and fuel was allowed to flow out of the nacelle and onto the concrete pad below to form a pool. When the flow to the pool totaled 25 gal (corresponding to a 100-ft^2 pool), the firefighter ignited the fuel in the nacelle and on the pad with a propane torch. After the fire was fully involved (Figure 4), a 15-s pre-burn was initiated before agent application began. Once the fire was fully extinguished, agent application ended and the extinguishment time and final weight were recorded. Total agent discharge and average flow rate were calculated based on the agent discharge time and the before and after extinguisher weight measurements.

Figure 4. Nacelle engine during the pre-burn process

A variation of this test was conducted with Firebane 1179 agent to evaluate performance on the engine fire alone, without the pool fire. After heating and allowing the engine to cool, fuel flow was adjusted to 4 gal/min and the fire was ignited immediately inside the nacelle, and the amount of fuel spilled on the concrete pad was minimized. Any fuel that happened to spill onto the pad and ignite was extinguished with a separate AFFF extinguisher during the test so that the pad fire did not interfere with the engine fire. The engine fire was then fought with Firebane 1179.

4. RESULTS AND DISCUSSION

4.1. Data

Table 1 is a summary of evaluation results. Complete data is given in Appendix A.

Table 1. Data Summary

Agent	%	Delivery System	Test	Pool Fire Size (ft^2)	Successful Extinguish-ment (pass/total)	Average Extinguish-ment Time (s)	Average Flow Rate (gal/min)	Average Agent Required for Extinguish-ment (gal)	Average Agent Density (gal/ft^2)
AFFF	3	Tri-Max 30	Engine + Pool	100	3/3	19	15	4.7	NA
1115	10	Tri-Max 30	Engine + Pool	100	2/4	100	12	19.9	NA
1179	100	Tri-Max 30	Engine Only	No Pool	3/5	38	11	6.7	NA
AFFF	3	CAFFS	Engine + Pool	100	3/3	11	43	7.6	NA
1115	100	CAFFS	Engine + Pool	100	0/2	-	-	-	-
1115	50	CAFFS	Engine + Pool	100	4/4	51	31	28.8	NA
1115	10	CAFFS	Engine + Pool	100	4/4	28	39	18.9	NA
1179	100	CAFFS	Engine Only	No Pool	6/7	13	33	6.4	NA
AFFF	3	Tri-Max 30	Pool	79	3/3	17	15	5.1	0.053
1115	100	Tri-Max 30	Pool	79	3/4	94	11	18.0	0.230
1115	10	Tri-Max 30	Pool	177*	4/4	37	13	8.4	0.057
* One test was done using a 78.5 ft^2 pool and the other three were done using a 176.7 ft^2 pool.									

4.2. Data Analysis

Each series of tests was treated as a binomial distribution for statistical analysis of pass-fail rate, and a nomograph of cumulative binomial distribution was used to determine confidence level and reliability. Average volumes of agents required to extinguish fires are shown, however because of the small number of trials done for each of the different conditions results should be used with caution and are shown for comparison only. The cost of the agent and the number of different firefighting scenarios evaluated precluded accomplishing additional trials.

4.3. Firefighting Agent Density

Firebane 1115 and 1179 were evaluated at 100-percent concentration, and Firebane 1115 was also evaluated diluted with 50 percent and 90 percent water. Table 2 shows the density as reported on the MSDS supplied by the manufacturer and the measured density. Density of the agents and the diluted agents was measured at room temperature using a Mettler Toledo Densito 30PX instrument, which had an accuracy of ± 0.001 g/cm^3 (0.00004 lb/in^3).

Table 2. Firebane Agent Density

Agent	MSDS Density	AFRL Measured Density
Firebane 1115	1.119 g/cm^3 (0.04043 lb/in^3)	1.1848 g/cm^3 @ 23.4 °C (0.042804 lb/in^3 @ 74.1 °F)
50% Firebane 1115	-	1.0950 g/cm^3 @ 23.3 °C (0.039559 lb/in^3 @ 73.9 °F)
10% Firebane 1115	-	1.0214 g/cm^3 @ 23.4 °C (0.036900 lb/in^3 @ 74.1 °F)
Firebane 1179	1.0-1.2 g/cm^3 (0.036-0.043 lb/in^3)	1.2277 g/cm^3 @ 23.5 °C (0.044353 lb/in^3 @ 74.3 °F)

4.4. AFFF

Three-percent AFFF comparison tests were conducted for each of the three fire scenarios: the CAFFS extinguisher engine nacelle tailpipe fire; the Tri-max 30 extinguisher engine nacelle tailpipe fire; and the Tri-max 30 extinguisher pool fire. Engine nacelle tailpipe fires for evaluating AFFF included the 100-ft^2 pool fires. Results are given in appendix A and are summarized in Table 1. Average flow rate from the Tri-Max 30 was 15 gal/min, and average flow rate from the CAFFS unit was 43 gal/min. All three test fires for each of the three fire scenarios were extinguished. For the three scenarios this correlates to 90-percent confidence of extinguishing 50 percent of the fires.

4.5. Firebane 1179

Performance of Firebane 1179 was initially evaluated against the engine nacelle tailpipe procedure while discharged from the CAFFS handline. Firebane 1179 is more viscous than AFFF which resulted in lower flow rates compared to AFFF. The initial fire was not extinguished and all observers, including representatives from GSL, agreed that additional attempts to extinguish the fire would not succeed because the agent had little effect on the pool fire. Following this test, JP-8 was spilled onto the concrete pad and ignited to evaluate Firebane 1179 performance on a JP-8 spill fire alone. A single attempt to extinguish the fuel spill pool fire on the concrete pad was attempted (see Figure 5), and all observers agreed that additional attempts to extinguish the engine fire would not succeed, again because the agent was ineffective on the pool fire.

The decision was made to evaluate Firebane 1179 on the engine fire only, without the pool fire under the engine. Detailed results are given in appendix A and are summarized in Table 1. Six of the seven fires were extinguished. Based on this result, Firebane 1179 at flow rates comparable to those from the CAFFS unit has a 95-percent confidence of extinguishing up to 50 percent of engine fires similar to the test protocol. Firebane 1179 was also evaluated against the engine fire protocol using the Tri-Max 30 extinguisher to determine the performance at a lower flow rate. The average agent discharge rate from the Tri-Max 30 was 10.5 gal/min. Three of five fires were extinguished and extinguishment times were generally longer at this flow rate than with the CAFFS handline. Using Firebane 1179 in a Tri-Max 30 there is 50-percent confidence of extinguishing 50 percent of these engine-only fires.


Figure 5. Firebane 1179 being applied to the engine protocol pool fire

4.6. Firebane 1115

Firebane 1115 performance was evaluated against pool fires and against the engine nacelle tailpipe fire test protocol including the 100-ft^2 pool fire. Engine nacelle fires were done with the CAFFS delivery system and the Tri-Max 30. Pool fires were done using only the Tri-Max 30. Initial results showed poor performance with the agent used at 100-percent concentration. The manufacturer recommended diluting the agent with 50 percent or 90 percent water for additional evaluations.

4.6.1. Firebane 1115 Engine Nacelle Tailpipe Evaluations

Firebane 1115 was evaluated against the engine nacelle tailpipe procedure using the CAFFS handline. When discharged at 100-percent concentration, the agent did not completely extinguish the first two fires. It was observed that the pool fire was not extinguished, which makes the engine fire almost impossible to extinguish due to constant re-ignition from the pool fire. Figure 6 illustrates that even when the pool fire was completely blanketed with Firebane 1115 the pool fire was not extinguished.

Figure 6. Firebane 1115 foam blanket during engine nacelle test

The manufacturer recommended diluting the Firebane 1115 50-percent by volume with water. Four tests were conducted with a 50-percent agent concentration, and the full results appear in appendix A and are summarized in Table 1. Figure 7 shows the 50-percent concentration foam blanket completely extinguishing the engine protocol pool fire. An additional four tests were conducted with 10 percent Firebane, 90 percent water solution. All eight fires were extinguished using the diluted Firebane solution. Results suggest that the most dilute concentration of Firebane 1115 is most effective. Each of the dilute solutions extinguished four of four test fires, meaning that there is 95-percent confidence that both solutions could extinguish at least 50 percent of similar fires at flow rates and volumes consistent with those in Table 1.

Figure 7. 50-percent Firebane 1115 foam blanket during engine nacelle test

Four tests were also conducted with 10-percent Firebane 1115 discharged at a lower flow rate with the Tri-Max 30. It was apparent from these tests that the Firebane 1115 in the Tri-Max 30 was near the limit of its ability to extinguish this fire. Data for the four tests indicates there is a 30-percent confidence of extinguishing half the fires with Firebane 1115 in a Tri-Max 30 unit.

4.6.2. Firebane 1115 Pool Fire Evaluations

Firebane 1115 was used in the Tri-max 30 extinguisher and evaluated against JP-8 pool fires at 100-percent concentration. A 10-ft diameter ring was used to contain the fuel in a 79-ft^2 area. Three of the four fires were extinguished, and complete data is given in appendix A and summarized in Table 1. The average extinguishment time for the three fires was 94 s, and the average area density of agent for extinguishment was 0.23 gal/ft^2 of pool fire area. Three successes in four attempts correspond to 70-percent confidence of extinguishing 50 percent of pool fires similar to the test protocol fire.

Firebane 1115 at a 10-percent concentration was also tested on pool fires with the Tri-Max 30 extinguisher. Data appears in appendix A and in Table 1. The first 79-ft^2 pool fire was extinguished in 25 s, significantly more quickly than any of the fires of the same size extinguished using 100-percent Firebane 1115, and so the pool size was expanded to 15-ft diameter, or 177ft^2, shown in Figure 8. All three 177 ft^2 fires were extinguished with the 10-percent Firebane solution. The average area density of agent required to extinguish the fires was 0.057 gal/ft^2. This result corresponds to a 95-percent confidence for extinguishing 50 percent of the pool fires of this size when applied at a rate and to an agent density comparable to those in Table 1.

Figure 8. 10-percent Firebane 1115 pool fire

4.7. Other Observations

The viscosities of the Firebane agents were not measured. However, from handling the agents it was obvious that both agents were more viscous than water and AFFF solution. This property

resulted in lower flow rates from the fire extinguishers, even when diluted, compared to AFFF. The higher viscosity of the Firebane agents increased the time necessary to fill the extinguishers. This was more noticeable with Firebane 1115. Gravity flow into hose fittings was slow and an electric pump that is typically used to increase transfer flow ran hot while transferring the agent.

5. CONCLUSIONS

At full concentration, which is required for freeze protection, neither Firebane 1115 or 1179 were effective at extinguishing 4 gal/min running fuel fires in a simulated aircraft engine and accompanying 100-ft^2 ground fire. AFFF applied at 15 gal/min extinguished this fire in an average of 19 s using about 5 gal of agent. Firebane 1179 at full concentration reliably extinguished 4 gal/min spraying fuel fires in a simulated aircraft engine when there was no ground fire. On JP-8 pool fires alone, Firebane 1179 was ineffective.

Firebane 1115 mixed 10 percent by volume with water was effective at extinguishing 4 gal/min running fuel fires in a simulated aircraft engine in combination with a 100-ft^2 ground fire. In four out of four trials using a CAFFS unit flowing agent at 39 gal/min, the fire was extinguished in an average of 28 s using 19 gal of solution. By comparison, AFFF flowing at 43 gal/min from a CAFFS unit extinguished this same fire in an average of 11 s using 8 gal of solution. Firebane 1115 mixed 50 percent by volume with water was also effective on this fire but took more time and agent than Firebane 1115 mixed 10 percent by volume with water. Firebane 1115 diluted with water is not freeze protected to -49 °F, as it is in its concentrated state, but neither is a 3-percent premixed solution of MILSPEC AFFF. Presently, there is no freeze protected AFFF that meets the MILSPEC standard.

Firebane 1115 at full concentration extinguished three of four JP-8 pool fires in an average of 94 s when applied at a rate of 11 gal/min. An average of 18 gal of solution was applied, which corresponds to an area coverage density of 0.23 gal/ft^2 of pool fire area. Mixed 10 percent by volume with water, Firebane 1115 extinguished four of four pool fires in an average time of 37 s and required 8.4 gal of solution, corresponding to an area density of 0.057 gal/ft^2 of pool fire area. For comparison, 3-percent AFFF extinguished three of three pool fires at an average area density of 0.053 gal/ft^2.

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Appendix A: Test Data and Results

Test Number	Agent	%	Delivery System	Test	Fire Size (ft² pool area)	Ambient Temp. (°F)	Relative Humidity (%)	Wind Speed	Extinguisher Initial Weight (lb)	Extinguisher Final Weight (lb)	Agent Used (lb)	Successful Extinguish-ment	Extinguish-ment Time (s)	Agent Discharge Time (s)	Agent Density (lb/gal)	Average Flow Rate (lb/s)	Average Flow Rate (gal/min)	Agent Required for Extinguishment (gal)	Agent Density (gal/ft^2)	Notes
121301	1179	100	CAFFS	Engine Nacelle	100	55	86.3	2.3	-	-	n/a	No	-	67	10.24	-	-	-	-	
122922	1179	100	CAFFS	Engine Nacelle	Engine Only	53	71	1.3	4130	3880	250	Yes	41	52	10.24	4.81	28.2	19.2	-	
122923	1179	100	CAFFS	Engine Nacelle	Engine Only	58	70.1	2.1	3860	3750	110	Yes	7	25	10.24	4.40	25.8	3.0	-	
122924	1179	100	CAFFS	Engine Nacelle	Engine Only	58	69.3	2.1	3740	3660	80	Yes	7	16	10.24	5.00	29.3	3.4	-	
122925	1179	100	CAFFS	Engine Nacelle	Engine Only	58	64.8	1.9	3660	3580	80	Yes	5	11	10.24	7.27	42.6	3.6	-	
122926	1179	100	CAFFS	Engine Nacelle	Engine Only	59	63.2	2.5	3490	3190	300	No	-	60	10.24	5.00	29.3	-	-	
122927	1179	100	CAFFS	Engine Nacelle	Engine Only	62.1	57	2.8	3190	3100	90	Yes	11	16	10.24	5.63	33.0	6.0	-	
122928	1179	100	CAFFS	Engine Nacelle	Engine Only	62.6	57	2.1	3100	3040	60	Yes	5	9	10.24	6.67	39.1	3.3	-	
123029	1179	100	Tri-Max 30	Engine Nacelle	Engine Only	72	77	2	508	471	37	Yes	6	19	10.24	1.95	11.4	1.1	-	
123030	1179	100	Tri-Max 30	Engine Nacelle	Engine Only	70.7	71	2.8	470	371	99	Yes	39	52	10.24	1.90	11.2	7.2	-	
123031	1179	100	Tri-Max 30	Engine Nacelle	Engine Only	75	66.6	0	493	249	244	No	-	139	10.24	1.76	10.3	-	-	
123032	1179	100	Tri-Max 30	Engine Nacelle	Engine Only	70	70	2.8	501	361	140	Yes	68	79	10.24	1.77	10.4	11.8	-	
123033	1179	100	Tri-Max 30	Engine Nacelle	Engine Only	73	61	5.2	502	346	156	No	-	97	10.24	1.61	9.4	-	-	
121302	1115	100	CAFFS	Engine Nacelle	100	73	57	3	4000	3760	240	No	-	61	9.88	3.93	23.9	-	-	
121303	1115	100	CAFFS	Engine Nacelle	100	74	60	2	-40	-215	n/a	No	-	71.0	9.88	-	-	-	-	
121404	1115	50	CAFFS	Engine Nacelle	100	56	76	1	3000	2670	330	Yes	47	71	9.14	4.65	30.5	23.9	-	
121405	1115	50	CAFFS	Engine Nacelle	100	66	72	6	0	-120	n/a	Yes	30	32.0	9.14	-	-	-	-	
121406	1115	50	CAFFS	Engine Nacelle	100	74	54	3.5	3180	2840	340	Yes	66	73	9.14	4.66	30.6	33.6	-	
121407	1115	50	CAFFS	Engine Nacelle	100	75	49	3	2920	2630	n/a	Yes	60	65.0	9.14	-	-	-	-	
121508	1115	10	CAFFS	Engine Nacelle	100	57	99	0	3760	3535	n/a	Yes	25	29.0	8.52	-	-	-	-	
121509	1115	10	CAFFS	Engine Nacelle	100	67.8	84.4	2.1	3500	3380	120	Yes	18	21	8.52	5.71	40.2	12.1	-	
121512	1115	10	CAFFS	Engine Nacelle	100	76	66	4.5	3430	3220	210	Yes	31	36	8.52	5.83	41.1	21.2	-	
121513	1115	10	CAFFS	Engine Nacelle	100	72.4	66.6	4.3	3200	2980	220	Yes	39	43	8.52	5.12	36.0	23.4	-	
121510	1115	10	Tri-Max 30	Engine Nacelle	100	73	69	2.3	438	204	234	Yes	110	155	8.52	1.51	10.6	19.5	-	
121511	1115	10	Tri-Max 30	Engine Nacelle	100	76	66	3.2	444	215	229	No	-	146	8.52	1.57	11.0	-	-	
31634	1115	10	Tri-Max 30	Engine Nacelle	100	81.7	58.9	4	436	215	221	No	-	140	8.52	1.58	11.1			
31635	1115	10	Tri-Max 30	Engine Nacelle	100	79.6	68	4.5	436	250	186	Yes	90	97	8.52	1.92	13.5	20.3		
121618	1115	100	Tri-Max 30	Pool	79	75	72	2	485	225	260	Yes	132	137	9.88	1.90	11.5	25.3	0.321	
121619	1115	100	Tri-Max 30	Pool	79	75	72	5.5	486	365	121	Yes	59	64	9.88	1.89	11.5	11.3	0.143	
121620	1115	100	Tri-Max 30	Pool	79	73	76.1	3.1	481	303	178	Yes	91	94	9.88	1.89	11.5	17.4	0.221	
121621	1115	100	Tri-Max 30	Pool	79	75	75	4.7	482	217	265	No	-	150	9.88	1.77	10.7	-	-	
121614	1115	10	Tri-Max 30	Pool	79	65	80	4	438	383	55	Yes	25	32	8.52	1.72	12.1	5.0	0.064	
121615	1115	10	Tri-Max 30	Pool	177	68	78.5	4.1	445	355	90	Yes	41	46	8.52	1.96	13.8	9.4	0.053	
121616	1115	10	Tri-Max 30	Pool	177	74	76	3	446	340	106	Yes	46	54	8.52	1.96	13.8	10.6	0.060	
121617	1115	10	Tri-Max 30	Pool	177	74	76	3.6	445	349	96	Yes	37	48	8.52	2.00	14.1	8.7	0.049	
110901	AFFF	3	CAFFS	Engine Nacelle	100	66	84	2.1	-	-	-	Yes	14		8.35		42.8	10.0		1
111502	AFFF	3	CAFFS	Engine Nacelle	100	68.7	83.5	3.3	-	-	-	Yes	9		8.35		42.8	6.4		1
31936	AFFF	3	CAFFS	Engine Nacelle	100	78.8	62.5	2	3680	3555	125	Yes	9	21	8.35	5.95	42.8	6.4		
113003	AFFF	3	Tri-Max 30	Engine Nacelle	100	58	50	1.5	-	-	-	Yes	18		8.35		15.0	4.5		2
113004	AFFF	3	Tri-Max 30	Engine Nacelle	100	60	50	5	-	-	-	Yes	15		8.35		15.0	3.8		2
31937	AFFF	3	Tri-Max 30	Engine Nacelle	100	81.2	69.4	3	435	365	70	Yes	24	35	8.35	2.00	14.4	5.7		
113001	AFFF	3	Tri-Max 30	Pool	79	55	55	5	-	-	-	Yes	12		8.35		15.0	3.0	0.038	2
113002	AFFF	3	Tri-Max 30	Pool	79	55	57	6	-	-	-	Yes	17		8.35		15.0	4.3	0.054	2
32038	AFFF	3	Tri-Max 30	Pool	79	69.1	90.6	4	448	397	51	Yes	21	25	8.35	2.04	14.7	5.1	0.065	

Note 1: Average flow rate based on time to empty agent from a full CAFFS unit.

Note 2: Average flow rate based on time to empty agent from a full Tri-Max unit.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

°F	degrees Fahrenheit
%	percent
AFFF	Aqueous Film Forming Foam
AFRL	Air Force Research Laboratory
CAF	Compressed Air Foam
CAFFS	Combined Agent Fire Fighting System
cm^3	cubic centimeter
ft^2	square feet
g	grams
gal/min	gallons per minute
GSL	Global Safety Labs Inc.
GWP	Global Warming Potential
in	inch
in^2	square inches
in^3	cubic inches
JP-8	Jet Propellant 8 (i.e. Jet Fuel)
lb	pounds
lb/in^2	pound/square inch
MILSPEC	Military Specification
min	minute
MSDS	Material Safety Data Sheet
mi/h	miles per hour
ODP	Ozone Depletion Potential
pre-burn	Amount of time fire is allowed to burn after it extends over the full extent of a pool and before extinguishment begins.
s	second
UL	Underwriters Laboratory
USA	United States Army
USAF	United States Air Force